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## **A STUDY OF FIRST-MONTH SPACE MALFUNCTIONS**

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16. Abstract  <p>The study examines the first-month space performance of 57 Goddard Space Flight Center spacecraft. It is a sequel to a previous study of first-day space malfunctions of the same 57 spacecraft. A total of 154 malfunctions, of which 88 were classified as failures, have been summarized by year of occurrence, by major subsystem of a spacecraft, by type of defect, and by severity. Of the 57 spacecraft, 45 had one or more failures during the first month in space. However, the mission criticality data show that, of the 154 malfunctions, less than 10 percent would have resulted in major loss (50-100 percent) to the mission, and due to redundancy, only 5 percent did result in major loss to the mission.</p> <p>The data show that more than 50 percent of the first month's failures occurred in the first operational day in space. The data also show that, for the first month in space, the ratio of system-test failures to space failures for various devices ranged from 3 to 1 up to 10 to 1. For six spacecraft programs, the ratios of test to space failures ranged from 2 to 1 up to 8 to 1.</p>			
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# **A STUDY OF FIRST-MONTH SPACE MALFUNCTIONS**

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## **INTRODUCTION**

The space age brought with it many new problems in many disciplines. One problem was how best to demonstrate that a spacecraft was ready for launch. Testing, including environmental testing, was recognized as a necessity. However, the amount and levels of testing as well as the requirements for mandatory testing were unknown. This uncertainty permitted a wide range of test philosophy, application, and practice.

At Goddard Space Flight Center the basic test philosophy included a strong system-environmental test program, including testing of the flight spacecraft (references 1 and 2). This philosophy did not preclude testing at subsystem level and below, but made that level of testing optional at the discretion of the Project Manager. Previous publications (references 3 and 4) have covered some aspects of the test and space results attained with this philosophy.

A previous study, entitled "A Study of First-day Space Malfunctions" (NASA TN D-6474, September 1971, reference 4) was made using data from 57 unmanned spacecraft developed under the management of the Goddard Space Flight Center. The present study, complementing the first, covers the malfunctions which occurred in the same 57 spacecraft during the first 30 days in space.

## **DATA BASE**

The 57 spacecraft used for the data base included the following:

- Meteorological spacecraft (4),
- Astronomical observatories (2),
- Geophysical observatories (6),
- Solar observatories (6),
- Applications technology spacecraft (6),
- Interplanetary monitoring platforms (7),
- Operational weather spacecraft (12),
- Miscellaneous scientific missions (14).

The experiments and subsystems for these spacecraft have been provided by various organizations, including Goddard Space Flight Center, other government agencies, universities, and aerospace companies. Eighteen of the spacecraft received a full system test at Goddard Space Flight Center, and 39 received a full system test in a contractor's facility. Figure 1 depicts the daily number of malfunctions (and failures) for the first month in space of the 57 spacecraft. This figure contains 12 more malfunctions than a similar figure in reference 4 because of additional information reported. Figure 2 contains the same data but arranged in a cumulative presentation. Figure 3 displays the first month's failures by day of occurrence with the failures identified as experiment or spacecraft.

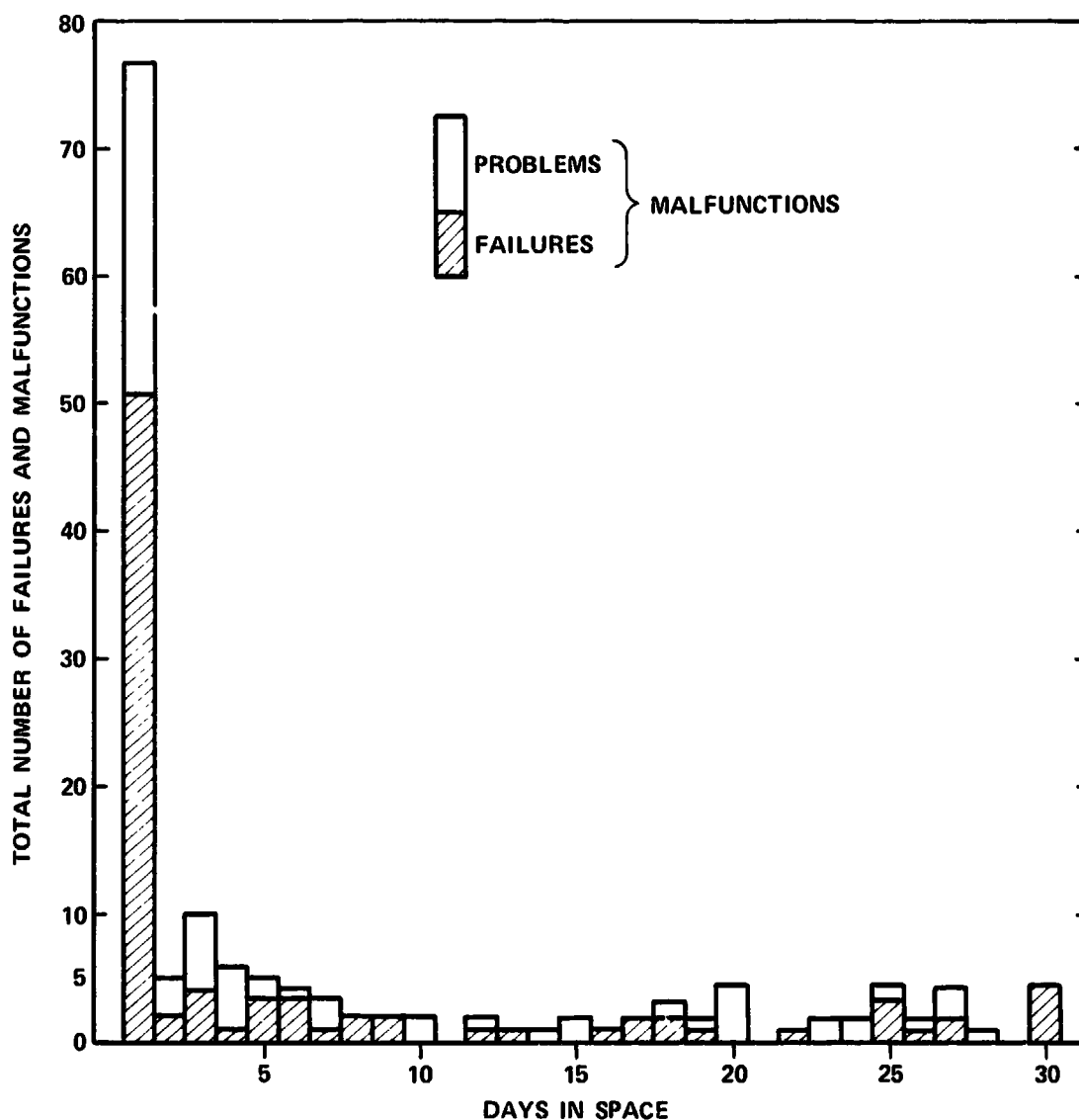


Figure 1. Daily Malfunctions for First Month in Space of 57 Unmanned Spacecraft

The terms problem, failure, and malfunction will be encountered throughout this report, and an understanding of the differences between them is necessary. The following definitions will be applicable:

- A problem is any substandard performance or partial loss of function which is not sufficient to be classed as a failure.
- A failure is the loss of operation of any function, part, component, or subsystem, whether or not redundancy permitted recovery of operation.
- A malfunction is any performance outside the specified limits and can be either a failure or a problem.

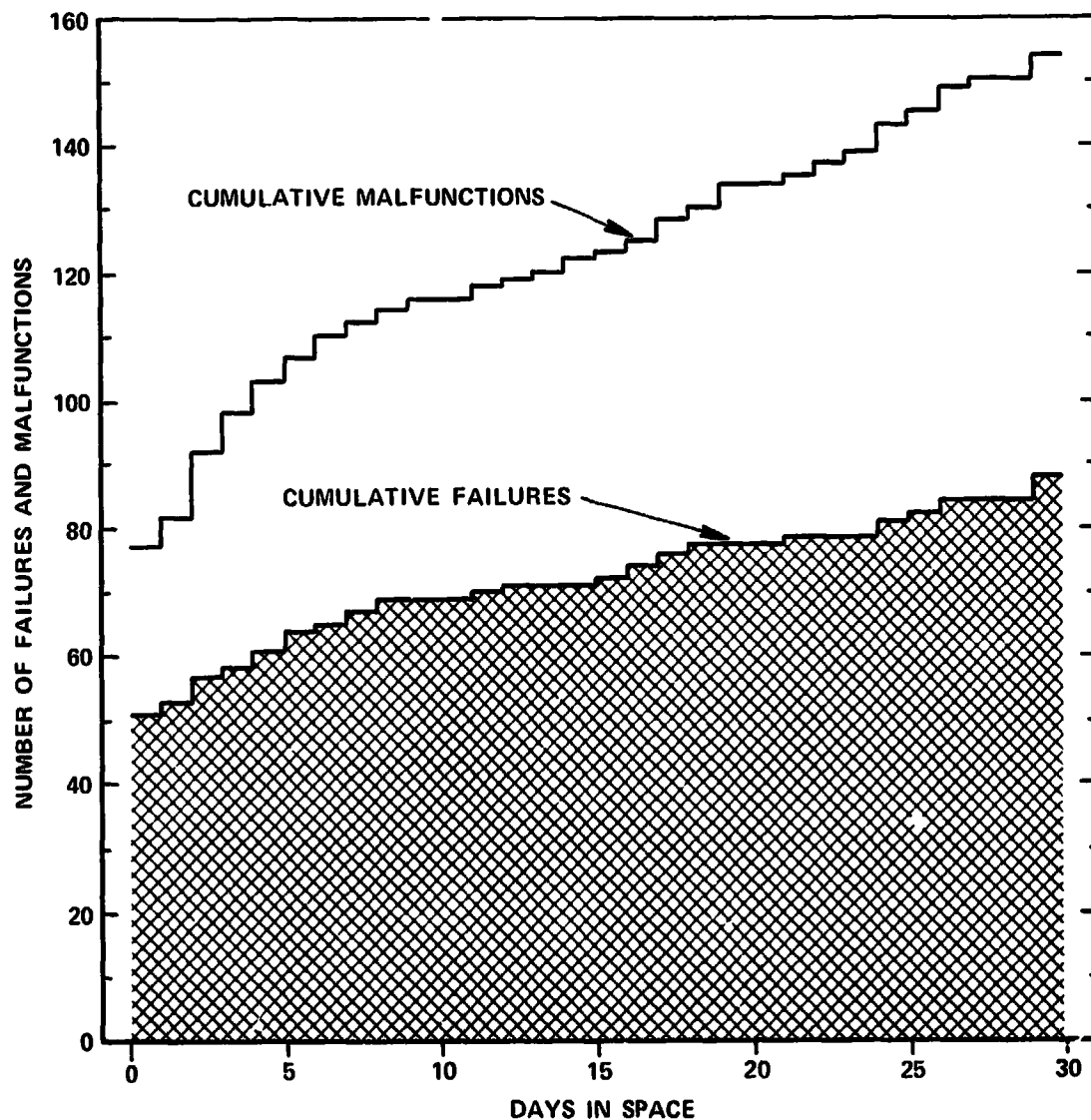


Figure 2. Cumulative Daily Malfunctions for First Month in Space on 57 Spacecraft

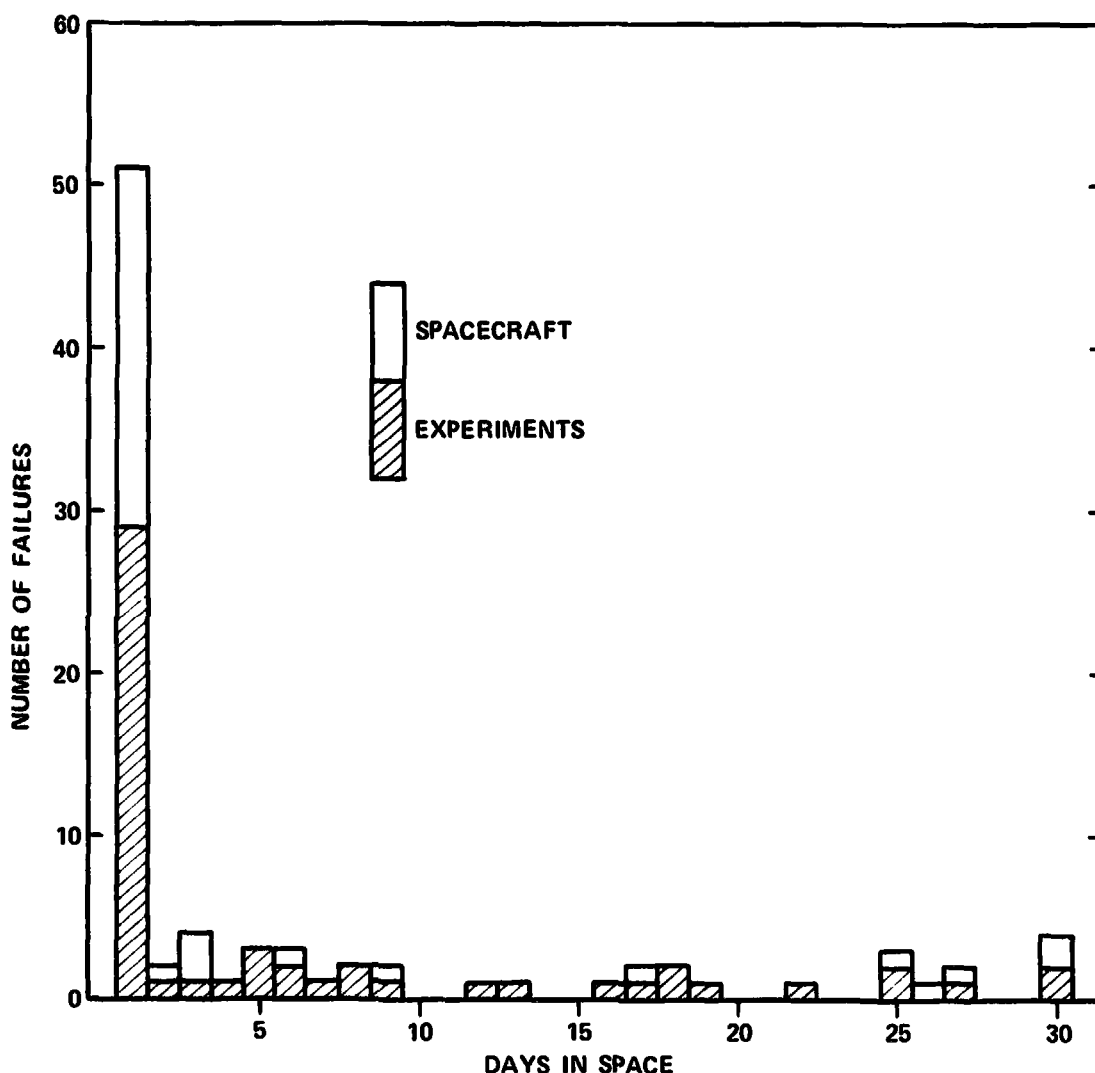


Figure 3. Daily Failures of Experiments During First Month in Space on the 57 Spacecraft

Table 1 lists the first-month failures and malfunctions for each year from 1960 to 1970. The data also include the number of spacecraft, together with the number without failures or malfunctions. Table 2 categorizes the 88 failures and 154 malfunctions according to the type of device involved, such as mechanical, electrical, electromechanical, pyrotechnic, and miscellaneous. Table 3 classifies the failures and malfunctions by spacecraft functions; that is, experiments, command and data handling, stabilization and control, power, or structure.

The data from table 1 on the number of first-month space failures (and malfunctions) per spacecraft are plotted for each year from 1960 to 1970 in figure 4. The average number of failures

**Table 1**  
**First-month Malfunctions of 57 Unmanned Spacecraft**

Launch Year	Number of Spacecraft	Number of Failures	Number of Malfunctions	Number of Spacecraft Without Failures	Number of Spacecraft Without Malfunctions
1960	2	2	7	0	0
1961	2	2	5	0	0
1962	8	6	13	3	2
1963	6	7	10	1	0
1964	8	9	11	4	4
1965	7	14	20	2	1
1966	6	9	16	0	0
1967	6	13	15	0	0
1968	4	9	25	1	0
1969	7	12	23	1	1
1970	1	5	9	0	0
Total	57	88	154	12	8

per spacecraft for the first month in space is about 1.5 for the 11-year period. There is a great deal more variation in the malfunctions per year than in the failures per year. No consistent improvement over the 11-year period is in evidence for failures or malfunctions.

The data in figure 4 could be unduly influenced by multiple malfunctions in a few spacecraft. To examine how many spacecraft were involved, figure 5 was developed to show the first-month space performance for each year from 1960 to 1970 in a different way. This display shows the percent of spacecraft with a failure in the first month in space for each of the 11 years. From figure 5 the failures are seen to occur in at least 50 percent of the spacecraft each year, and in five of the years, 100 percent of the spacecraft had one or more failures during the first month in space. Similar data are shown for the first day in space for convenient comparison.



**Table 2**  
**Classification of First-month Space Malfunctions From**  
**57 Spacecraft by Type of Device**

Type of Device	Failures		Total Malfunctions	
	Number	Percent	Number	Percent
Electrical	57	64	92	59
Electromechanical	13	15	32	21
Mechanical	10	11	18	12
Pyrotechnic	4	5	4	3
Miscellaneous	4	5	8	5
Total	88	100	154	100

**Table 3**  
**Classification of First-month Space Malfunctions From**  
**57 Spacecraft by Spacecraft Function**

Spacecraft Function	Failures		Malfunctions	
	Number	Percent	Number	Percent
Experiment	53	60	72	47
Command and Data Handling	12	14	31	20
Stabilization and Control	6	7	22	14
Power	8	9	14	9
Structure	4	4	9	6
Other	5	6	6	4
Total	88	100	154	100

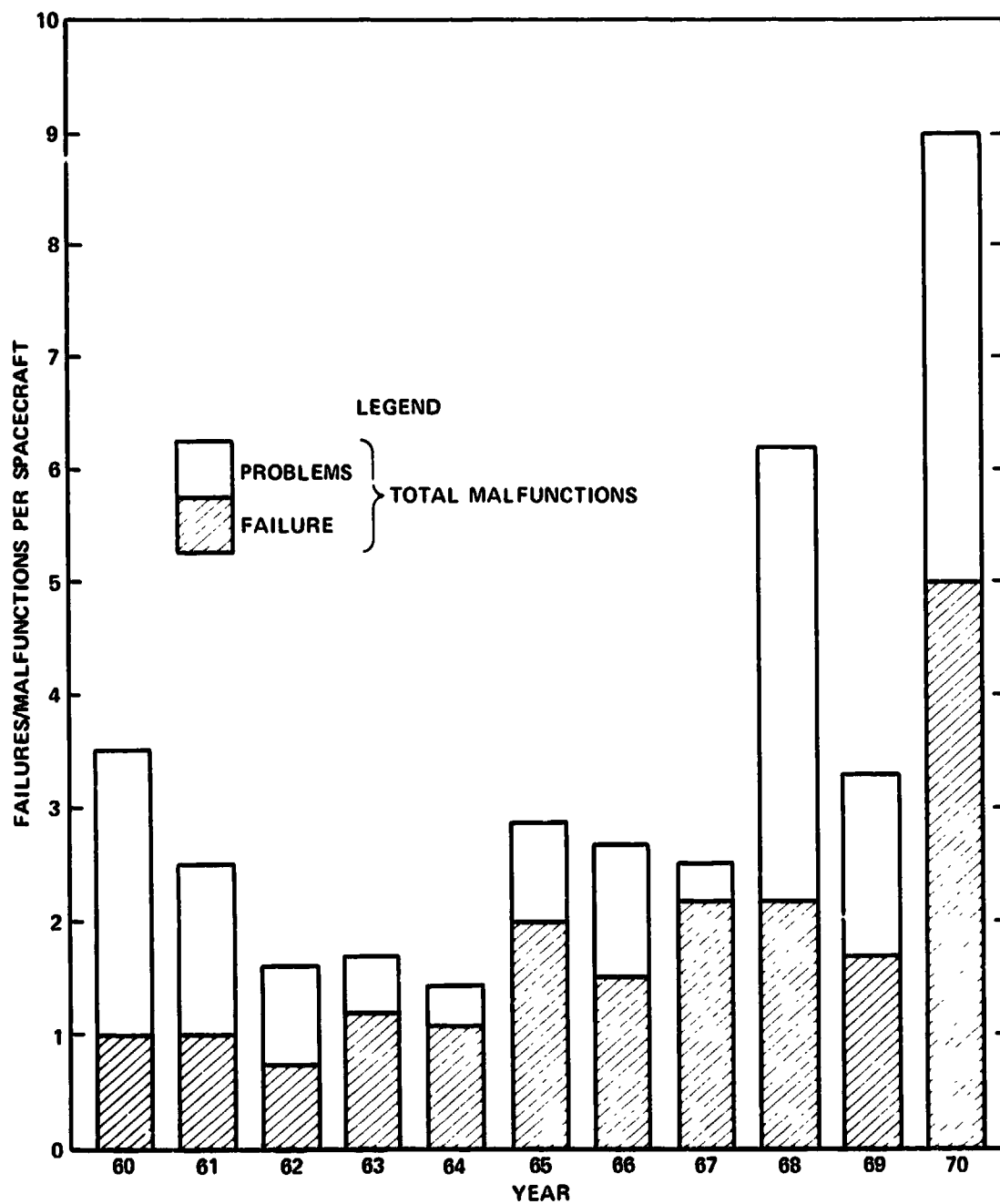


Figure 4. Malfunctions Per Spacecraft Per Year During First Month in Space for 57 Spacecraft

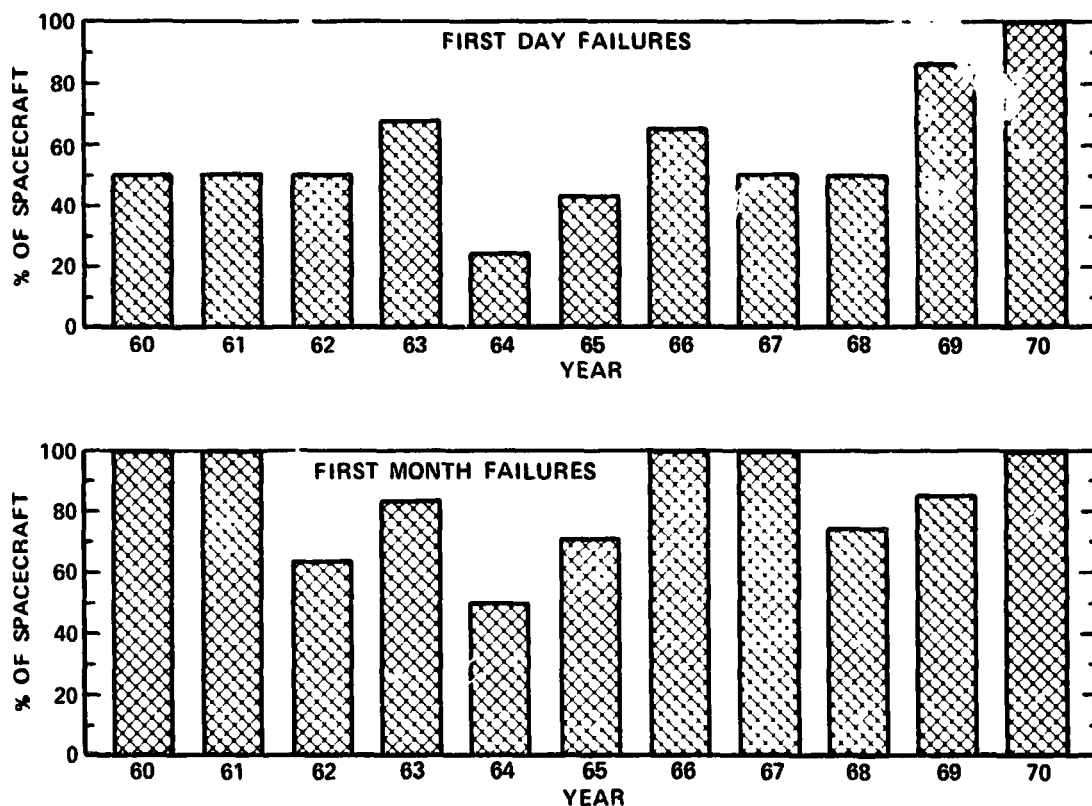


Figure 5. First-day and First-month Space Performance of GSFC Spacecraft, 1960-1970

### LIMITATIONS ON DATA

The data base for this report is considered to be comprehensive and representative. Nevertheless, some limitations need to be kept in mind when assessing or utilizing the results. The data are necessarily based on reported malfunctions. Some difference between reported and actual malfunctions is considered likely, based on the wide spectrum of individuals responsible for reporting a malfunction. Although there is no way to quantify the difference, it is thought to be small. This situation emphasizes the fact that the malfunction data should be considered a minimum.

The problem of radio-frequency interference (RFI), including spurious commands, has been purposely omitted from this study. This specialized problem has varied widely among satellites, orbits, location and power of ground-based energy sources, and command systems. In some cases the problem required a special investigation. For instance, an early spacecraft had 400 anomalous command states during the first year in space. Inclusion of such data would have obscured the findings of this study. As a final comment, RFI testing of a spacecraft before launch is considered as important now, if not more so, as in the early days of the space program.

Ground station problems are another category which has not been included in this study. In the main, these are temporary, equipment-related, and personnel-related events. When a malfunction was definitely ascribed to a spacecraft, it was then included as part of this study.

## **CRITICALITY OF MALFUNCTIONS**

The 154 malfunctions on the 57 spacecraft include items of differing importance or criticality and also include critical malfunctions which were not serious because redundancy permitted complete fulfillment of the desired function. Another aspect of criticality is that the effect of the malfunction on the mission can be completely different from the effect on the component. To aid in the discussion of criticality, two terms are defined:

- **Mission criticality**—a measure of the effect of a malfunction on the achievement of the mission objectives. The loss is given as a percentage of the mission objectives.
- **Component criticality**—a measure of the effect of a malfunction on the operation of a component. The loss is given as a percentage of component operation.

Mission and component criticality can each be considered with and without redundancy. Figure 6 gives some perspective on the distribution of the malfunctions with respect to mission criticality. Seventy-four percent of the malfunctions are classified as minor loss to the mission, assuming no redundancy. With redundancy, the malfunctions classified as minor loss to mission are 86 percent. Another aspect of the benefit from redundancy is that the benefit is extended to each of the three significance classifications (catastrophic, major, and significant).

Figure 7 shows the component criticality distributions of malfunctions. Looking at the distribution, which assumes no redundancy existed, the majority (56 percent) of the malfunctions are significant. Further, about 37 percent of the malfunctions are catastrophic losses of components. The criticality distribution of malfunctions, which shows the effect of redundancy, indicates that redundancy has effectively reduced the percentage of significant malfunctions from 56 to 34 percent. Figure 7 further shows that the percentage of catastrophic failures has been reduced from 37 to 24 percent through the benefits of redundancy.

## **RELATIONSHIP OF SYSTEM-TEST AND FIRST-MONTH SPACE PERFORMANCE**

The data presented have shown that the first-month space malfunctions are numerous (154 for 57 spacecraft). However, their effect on mission performance has been significant in only about 14 percent of the occurrences. The effect on component performance, on the other hand, has been significant in over 30 percent of the occurrences. These data raise the questions of how good has the system-test program been, and what kind of significant malfunctions escape the tests.

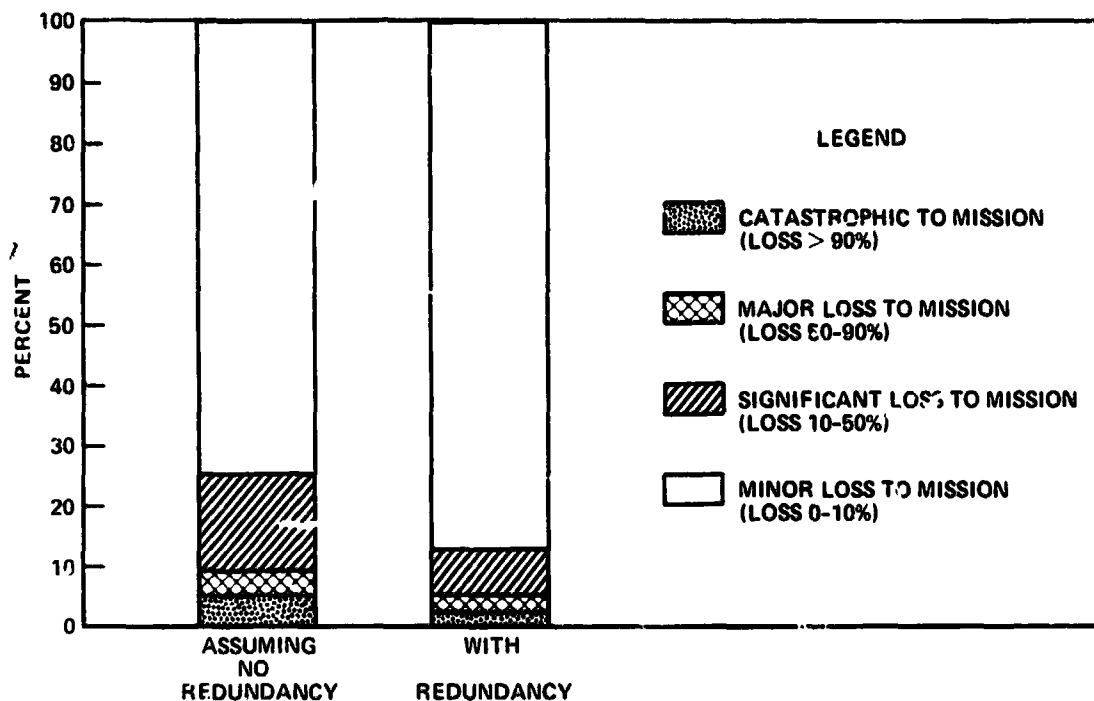


Figure 6. Mission Criticality of First-month Space Malfunctions for 57 Unmanned Spacecraft

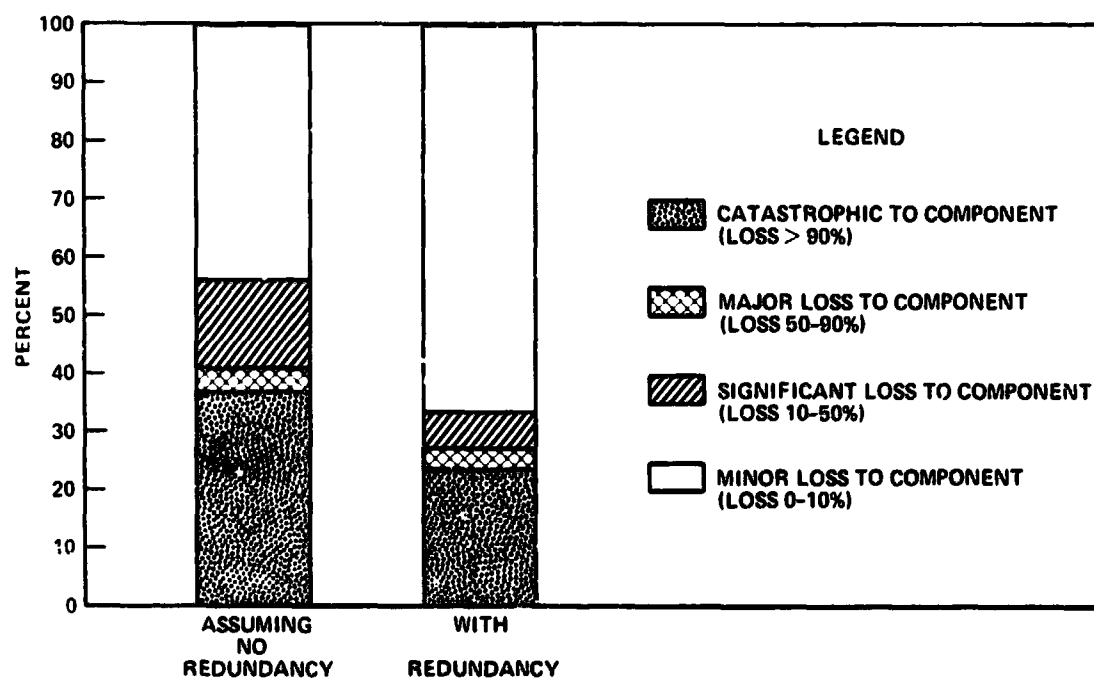


Figure 7. Component Criticality of First-month Space Malfunctions for 57 Unmanned Spacecraft

An overall view of the relationship of space performance to the system tests is shown in figure 8. The data base for this comparison is smaller than the one used up to this point. The data needed were available for 39 of the 57 spacecraft used in the previous part of the report. Figure 8 shows a total of 1043 malfunctions in the system tests and a total of 104 malfunctions in the first month in space. These totals have been segregated by types of devices involved, that is, electrical, mechanical, electromechanical, and miscellaneous. To develop some quantitative comparisons, the data from figure 8 have been used to produce table 4. It shows the ratio of the failures (and separately, the malfunctions) in systems tests to the failures in space. This ratio is 7 when considering the failures for all the devices and varies from 3 to 10 for the various types of devices.

When considering the malfunctions (failures plus problems) for all the devices, the ratio is 10 and varies from 4 to 13 for the various types of devices. In most cases the ratios indicate the system tests are more effective with respect to the malfunctions than with the failures. The ratio for the mechanical devices is an exception to this generalization and indicates that, for mechanical-type devices, the system tests have been more effective for screening failures than for total malfunctions.

Another comparison of system test performance with the first month in space was made. This time the data were segregated by program. Program, as used here, indicates that all the spacecraft had a similar mission objective and usually were made by the same manufacturer. As an example, all the Interplanetary Monitoring Platforms (IMPs) were grouped as one program. Table 5 shows the ratio, for each program, of the number of failures and malfunctions in the system tests compared to the failures of the first month in space. In all programs the ratios were higher for malfunctions than for failures. The data show that although problems are, in general, more numerous than failures in the system tests, they are more effectively eliminated than the failures. An interesting feature of table 5 is the data on failures. The failures per spacecraft in the environmental-system tests range from 5 to 31.5 for the seven different programs. (Part of this spread can be attributed to the variation in the number of components and complexity.) The range of failures per spacecraft for the seven programs for the first month in space is 0.9 to 4.2. In each case, ground test and space, the highest failure rate came from the same program. When this program is deleted, the range (and also the standard deviation) of failures for both ground test and space is reduced by 45 percent or more. This program should be considered separately when using these data to look for trends and relationships. The remaining six programs have surprisingly similar performance (for the first month in space) on the basis of the failures per spacecraft.

#### **ANALYSIS OF FIRST-MONTH SPACE PERFORMANCE**

An attempt was made to analyze the available data to determine the reasons for the escape of the defects from the system-test screen. Over 50 percent of the defects had to be classed as unknown reasons. For the other 50 percent, no prominent reason was in evidence: 9 percent were attributed to a time-dependent failure process; 7 percent had been

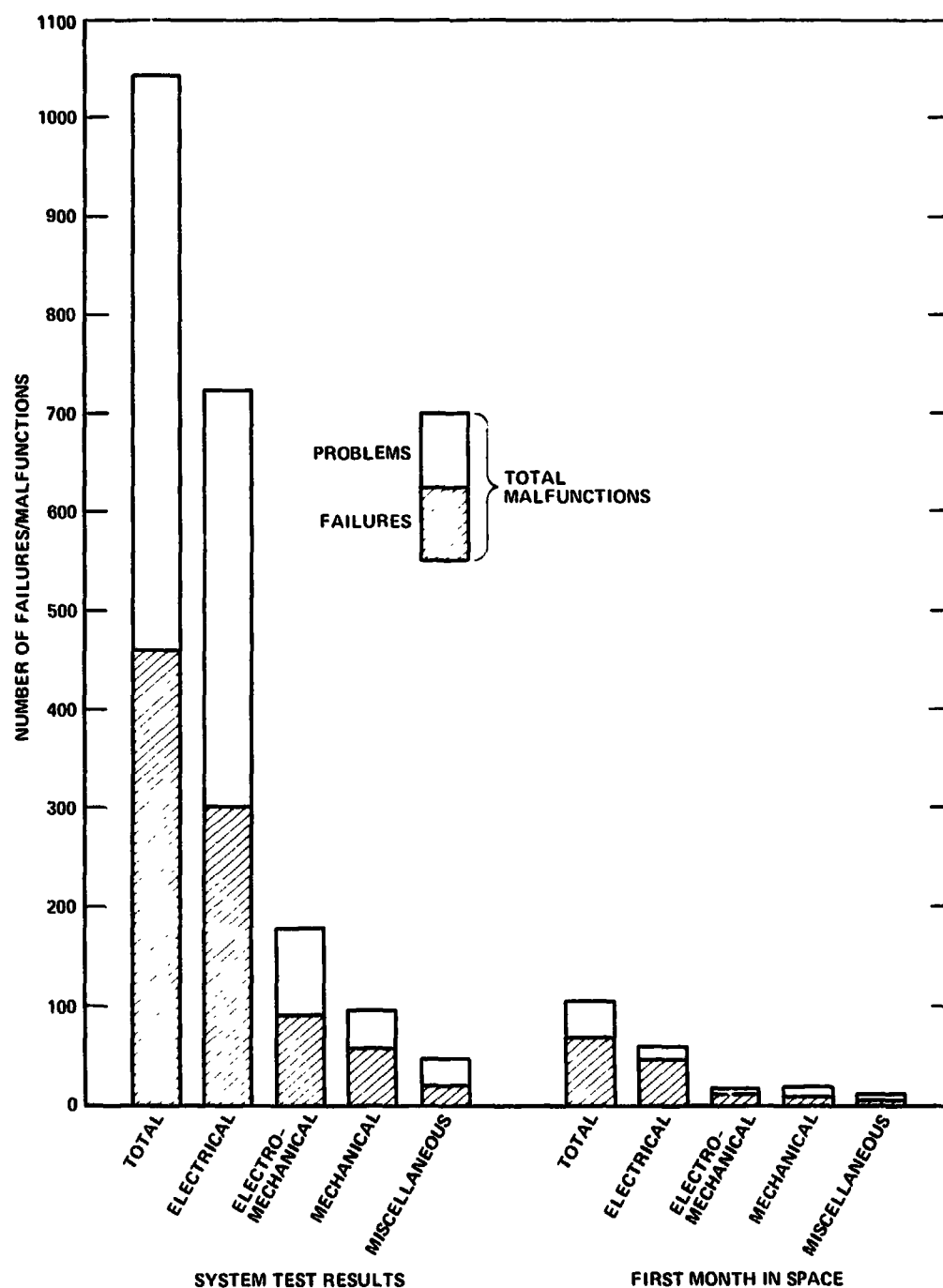


Figure 8. Comparison of System-test Performance with First-month Space Performance of 39 Unmanned Spacecraft

Table 4

**Comparison of System-test Performance with the First Month in Space  
of 39 Spacecraft by Type of Device**

Item Compared	Environmental System Tests		Space Performance		Ratio of System-test Performance to Space Performance	
	Failures	Malfunctions	Failures	Malfunctions	Failures	Malfunctions
Total Devices	463	1043	68	104	7	10
Electrical Devices	301	725	47	60	6	12
Electromechanical Devices	88	177	11	14	8	13
Mechanical Devices	57	97	5	18	10	5
Miscellaneous Devices	17	44	5	12	3	4

Table 5

**Comparison of System-test Performance with the First Month in  
Space of 39 Spacecraft by Program**

Spacecraft Program	No of Spacecraft	Malfunctions per Spacecraft				Ratio of System-test Performance to Space Performance	
		Environmental System Tests		Space Performance			
		Failures	Malfunctions	Failures	Malfunctions	Failures	Malfunctions
1	3	5.0	20.0	2	5.3	1.9	3.8
2	11	5.5	13.3	0.9	1.7	6.1	7.8
3	6	6.0	17.2	1.2	2.3	5.0	7.5
4	1	11.0	19.0	2.0*	2.0*	*	*
5	5	11.2	20.6	1.4	2.4	8.0	8.6
6	7	13.4	29.0	1.6	1.7	8.4	17.1
7	6	31.5	67.8	4.2	5.0	7.5	13.5

\* Catastrophic spacecraft failure first day in space.



detected previously in the system test, but not diverted; 6 percent had inadequate simulation; and the balance was distributed among several categories, such as decision to fly as is, not possible, not practical, inadequate detection capability, and hardware substituted after the system test was performed.

Another analysis examined the minimum level of hardware assembly at which the defect could have been detected. The results of analysis for the minimum level of assembly required are as follows:

System	49 percent,
Subsystem	29 percent,
Component	18 percent,
Below component	4 percent.

These results show that the system-level test is the one most required to detect the defects which occurred in the first month in space. On the other hand, over 50 percent could have been detected at a level of hardware assembly lower than the system level.

Three inferences are drawn from these results:

- They emphasize the importance of and validate the GSFC philosophy of reliance on the system level of testing.
- The results also show that the system level of testing does not constitute a 100-percent effective screen.
- Deletion of subsystem (and below) testing increases the risk of a space failure by overloading a test screen which is not 100-percent effective.

The purpose of this report has been the documentation and interpretation of the first-month space malfunctions. Some of the data (figures 1, 2, and 3) have shown the overriding influence of the first day in space compared to any other single day. Nevertheless, the subsequent days in the first month have been shown to be significant. While the separate presentation of all the data for days 2 through 30 has not been practical, some features of these malfunctions are worthy of note.

The percent of space failures attributed to experiments for the first day, first month, and days 2 through 30 is 55, 60, and 68, respectively. These data point out the most likely area for improving space performance.

Could a longer term, simulated space test of the spacecraft eliminate the failures detected in days 2 through 30 in space? This question was used on each failure with the following results: 22 percent of the failures were judged to be detectable in a longer term, thermal-vacuum test; an additional 35 percent of the failures were classed as unknown with respect to being detectable in a longer term, thermal-vacuum test; and the balance of the failures, 43 percent, were such that they were judged to be not detectable in a longer term thermal-vacuum test. These results are significantly different than when the same question was applied to the first-day failures. A summary of results follows in table 6.

**Table 6**  
**Percent of Space Failures Detectable in Longer Term,**  
**Thermal-vacuum Test**

Time When Space Defects Detected	Percent of Failures Detectable		
	Yes	No	Unknown
Day 1	6	88	6
Days 2-30	22	43	35
Days 1-30	13	68	19

The results for days 2 through 30 lead to the question, how much longer would the thermal-vacuum test need to be to eliminate the failures (22 percent) thought to be detectable in such a test. The only approach to answering the question was to assume that the number of space days to failure would be the same as additional days in a thermal-vacuum test. This approach indicated that for the specific spacecraft involved, the average thermal-vacuum test would have had to be increased from 15 to 20 days. A 20-day average test time would also be adequate to take care of the first-day space failures thought to be related to the thermal-vacuum environment. Note should be made that the results for day 1 show somewhat lower percentages for the Yes and Unknown categories than reported in reference 4, but the results agree in the overall indication that most of the first-day failures would not be prevented with a longer term thermal-vacuum test.

## CONCLUSIONS

The following conclusions are drawn from this study of first-month space malfunctions:

- Although the first day in space is by far the one on which a space malfunction is most likely to occur, a significant number of malfunctions have occurred during the balance of the first month.
- The malfunctions (likewise, failures) per spacecraft have not shown a decrease over the 10-year period.
- A large majority of the malfunctions did not result in significant loss to the component or the mission.
- For most devices 5 to 10 times as many failures are found in the system tests as occur in the first month in space.
- The majority of failures occur in electrical-type devices.

- The spacecraft function most likely to encounter failure is an experiment, with command and data handling next most likely.
- The GSFC philosophy of requiring system-level tests of flight spacecraft has been vital in obtaining an excellent space performance record, but it has not been applied so conservatively as to preclude all space failures.
- Reliance solely on system-level testing is not merited from this study.

Goddard Space Flight Center  
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Greenbelt, Maryland      February 1974  
502-22-11-01-51

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